

INTELLIGENT CONTROL OF AGRICULTURAL IRRIGATION SYSTEM BASED ON WIRELESS SENSOR AND ACTUATOR NETWORKS

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ABSTRACT

Optimizing water usage is the primary objective of intelligent and eco-friendly agricultural irrigation systems. In irrigation systems, the flow and pressure of water is usually regulated by controlling the position of the valve. The proportioning electronic actuator accepts a signal from the control system and moves the valve to allow the valve to partially open or close. Varying speed of pump motor can also control the usage of water. The integration of wireless sensor and actuator networks (WSANs) into irrigation management promises to overcome the excessive watering problem while providing additional functionality. This paper presents a case study on the use of WSAN for irrigation activities and investigates the application of fuzzy logic based valve aperture control. The results show that the proposed strategy can be effective in water flow control.

1 INTRODUCTION

Modern agriculture needs advanced technologies that can improve crop quality and production efficiency while protecting the environment [1]. Agricultural plants have a water requirement to survive and an optimum annual water requirement for maximum crop production. On the other hand, if the field is irrigated heavily with water, the plant may die due to the excessive irrigation. The key factor is not to add a drop of water more than required and not a drop less than needed for adequate plant growth [2].

Precision agriculture is a management strategy that uses information technologies to take decisions associated with crop production [3]. Many environmental variables that are relevant to precision agriculture, such as crop and soil properties and climate, vary in both time and space. In precision agriculture, one of the popular research topics is the crop irrigation scheduling and water quantity control for increasing water use efficiency. Seasonal water demand and peak daily use vary considerably from crop to crop and from one field to the next. Deciding when to irrigate and how much water to apply are the two most difficult decisions to make in managing irrigation systems [4]. In order to measure the soil moisture content in the active root zone, the soil moisture sensor is connected to an irrigation system controller. Thus

the farmers can monitor the individual crop types and potentially identify the various fertilizers, irrigation requirements [5,6].

In recent years, a new promising concept of wireless sensor networks (WSNs) has received much attention by researchers all over the world. WSNs can help the farmers to monitor soil parameters like depth of water, soil water tension (SWT) and system capacity for better crop yield [7,8]. In WSNs, the main objective is to gather raw sensor data or estimate the condition of the environment. The next step in the WSN evolution is their use not only monitoring, but also controlling the environment. WSANs are comprised of networked sensor nodes (SNs) and actuator nodes (ANs) communicating among each other via wireless links to perform distributed sensing and actuation tasks [9].

Intelligent systems operate without human supervision and respond to changes in their external environment. The computational capabilities of WSANs provide intelligence required to satisfy soil moisture requirements, while their wireless communication capabilities permit networking of individual components. In WSAN based smart irrigation monitoring and control system, a group of sensor and actuator nodes cooperate to satisfy the requirements for saving water without human intervention. So, by using collected data from sensors, actuators can perform desired actions accordingly.

In this paper, we describe the WSAN based intelligent irrigation system in detail that can be deployed either in the greenhouse applications or in the open field agriculture. The goal of this system is to monitor soil properties and optimized regulation of water being dispersed to an area. To regulate the watering operations, electronically controlled valves are used in the system and fuzzy control technique was applied to adjust the valve position. The fuzzy model based controllers has a rule base inference mechanism imitating the decision-making process of human brain for performing desired control processes on the systems. So, fuzzy logic offers high performance control of the time-varied nonlinear systems of which mathematical models aren't known.

Our approach that is conceptually different from the traditional irrigation approaches seeks the integration of the proportional control valves actuated within the design process. The remainder of the paper is organized as follows: Section 2 provides an overview of the system model and

describes the suggested WSN based irrigation system. Proposed fuzzy controller is explained in Section 3. The simulation result of the proposed method are also presented in this section through MATLAB Fuzzy Logic Toolbox. Finally, the paper is concluded in Section 4.

2 SYSTEM OVERVIEW

We consider a WSN with star topology in which the SNs are regularly deployed in the field. The designed system is applied for controlling drip irrigation as shown in Figure 1. The entire field is first divided into laterals such that each lateral contains only one sensor/actuator pair. So, there are a lot of laterals which are irrigated independently with control valves. In this semi-automated setup, the coordinator node (CN) operates as field controller and ensures the desired amount of water is applied to the crop and allow the user to monitor how the drip irrigation system performs. It is assumed that the CN is close to sensor/actuator pairs and then clearly single-hop communication is the best solution for our scenario. The SNs report data periodically to the CN and the reporting period is fixed. We also assume that each SN has to report one data packet per period. In order to obtain a collision-free schedule, the SNs should select non-overlapping time intervals for transmitting their packets as in the conventional TDMA with round robin fashion.

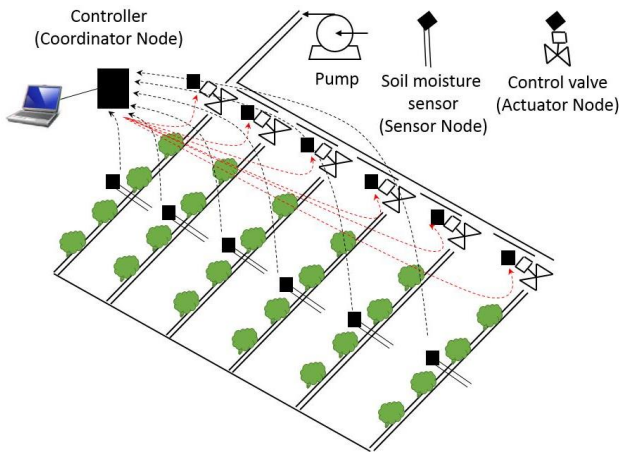


Figure 1: WSN based drip irrigation system model.

In traditional drip irrigation, sensors are buried in the ground at required depth and control valves are controlled by using automated controller to turn on and off. The purpose of this control loop is to maintain the controlled variable to desired value called as set point. So, the water will be maintained at the constant level until the water will reach the roots by going drop by drop. Once the soil has reached desired moisture level the sensors send a signal to the controller to turn off the relays, which control the solenoid valves. In ordinary solenoid valve only two stages of resolution are possible, fully open or fully closed.

In this paper, we focus on the proportional control. With this form of control, the valve positioned in intermediate positions in proportional to the difference between the set point and the measured real value. So, the actuator

continually searches for the proper position from full open to full close. A schematic of the components of the control system is shown Figure 2. The control system operates as follows: The SNs measure the actual values of SWT and water depth collected from soil moisture sensors in the same lateral line and send a signal back along the feedback path to the CN. The CN calculates the difference between the desired value and the measured value is known as the error signal and stimulates the related AN. The ANs respond to a signal received from CN and vary the flow of the water by driving valves. This in turn changes the condition of the process to the desired value.

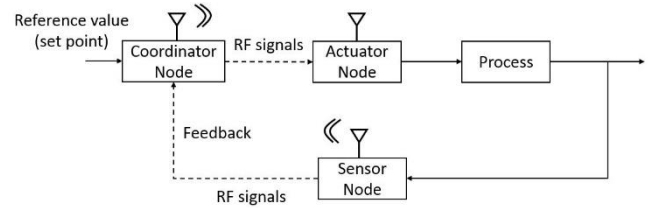


Figure 2: an illustration of signal flow in control system.

3 FUZZY CONTROLLER

Due to fact that the expected performance of traditional methods are not obtained, recent research in agricultural irrigation related soft control techniques like as fuzzy logic can contribute to reduction of waste water. The usual approach is to compute a fuzzy function on the system error by using a set of predefined rules [10]. Figure 3 shows the block diagram of the designed fuzzy PD controller.

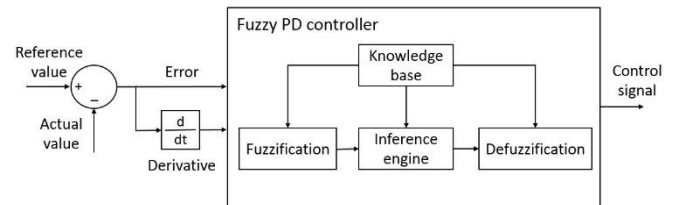


Figure 3: a block diagram of the fuzzy PD controller.

In order to control the water flow in the laterals, we use two parameters water depth error and its derivative. The error variable is calculated by taking the difference between the reference level and the current water depth at certain sampling times. It is expressed as,

$$error(n) = reference(n) - actual(n) \quad (1)$$

where n is discrete sampling time. Error derivative input variable is determined by the ratio of the difference between the current and previous error values to the sampling period. It is given by,

$$derivative(n) = \frac{error(n) - error(n-1)}{\Delta} \quad (2)$$

where Δ is sampling period. If sampling period is chosen as unity, the error derivative variable is simplified as change of error. We assume that the error values typically in the range from 0 to 30 cm and the universe of discourse for error derivative is chosen to be $[-2, 2]$ cm. Since the error value may change depending on the soil type, the controller performance can be increased by setting the sampling period. According to the input variables, the system output is calculated to control the valve opening position.

Membership functions for input and output variables are usually determined with the help of expert experience [10]. Fuzzy sets of the linguistic variables error, its derivative and valve opening are {VS:Very Small, S:Small, M:Medium, L:Large, VL:Very Large}, {N:Negative, Z:Zero, P:Positive} and {C:Closed, HC:Half Closed, M:Medium, HO:Half Open, O:Open}, respectively. Due to the computation simplicity, we have used triangular membership functions for both input and output fuzzy variables as defined in Figure 4, Figure 5 and Figure 6.

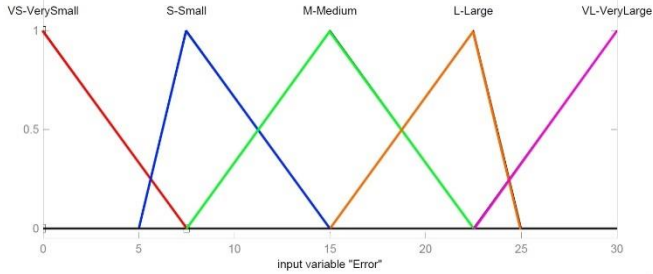


Figure 4: a membership function for error.

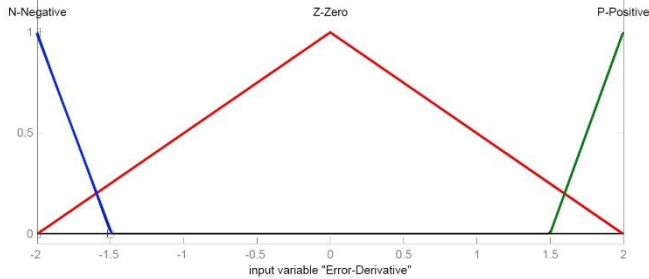


Figure 5: a membership function for error derivative.

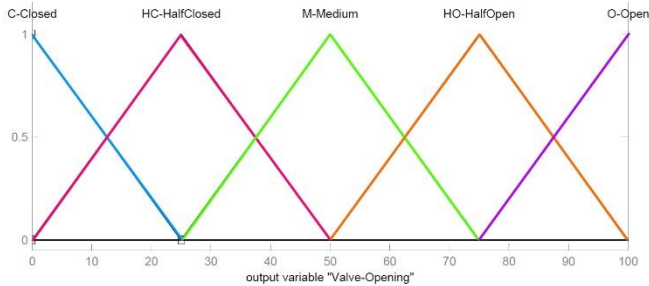


Figure 6: a membership function for valve opening.

Valve Opening			Error				
			VerySmall	Small	Medium	Large	VeryLarge
			VS	S	M	L	VL
Derivative	Negative	N	Closed	Closed	HalfClosed	HalfOpen	Open
	Zero	Z	Closed	HalfClosed	Medium	HalfOpen	Open
	Positive	P	Closed	HalfClosed	HalfOpen	Open	Open

Table 1: a rule base of designed fuzzy PD controller.

Fuzzy inference engine is responsible for decision making according to if-then rules database. The designed fuzzy rule base is given in Table 1. The Mamdani method is used for decision making and the defuzzification is done using mean value of maximum (MOM) method [11,12]. The control surface of designed fuzzy PD controller is represented in Figure 7. This plot gives the percent of valve opening versus error and error derivative.

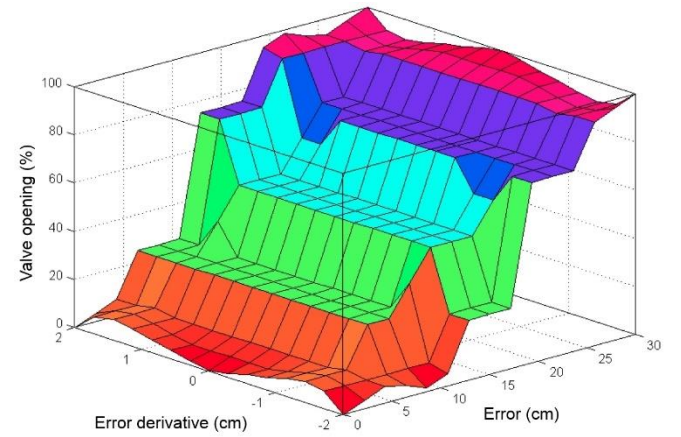


Figure 7: a control surface of designed fuzzy PD controller.

Soil moisture content change is a complex process and it has a certain relationship with the environmental factors. Hence, establishment of the precise mathematical model on the agricultural irrigation is almost impossible. In order to test the performance of proposed fuzzy PD controller, the valve opening control signal was monitored on a test set of water depth values by choosing reference level as 28 cm. As it can be seen from Figure 8, the changes in water level is measured along sampling points and the changes in control signal were obtained.

4 CONCLUSION

In this paper the design of a WSN based drip irrigation system is proposed, which is a closed loop control system for monitoring and managing activities more efficiently. The proposed intelligent irrigation system is a model to modernize the agriculture and enables farmers to provide irrigation to larger areas of plants with less water consumption and lower pressure. The advantages of using WSN are having the reduced wiring and piping costs, easier installation and maintenance in large fields. The system is applicable for different crops with small modifications.

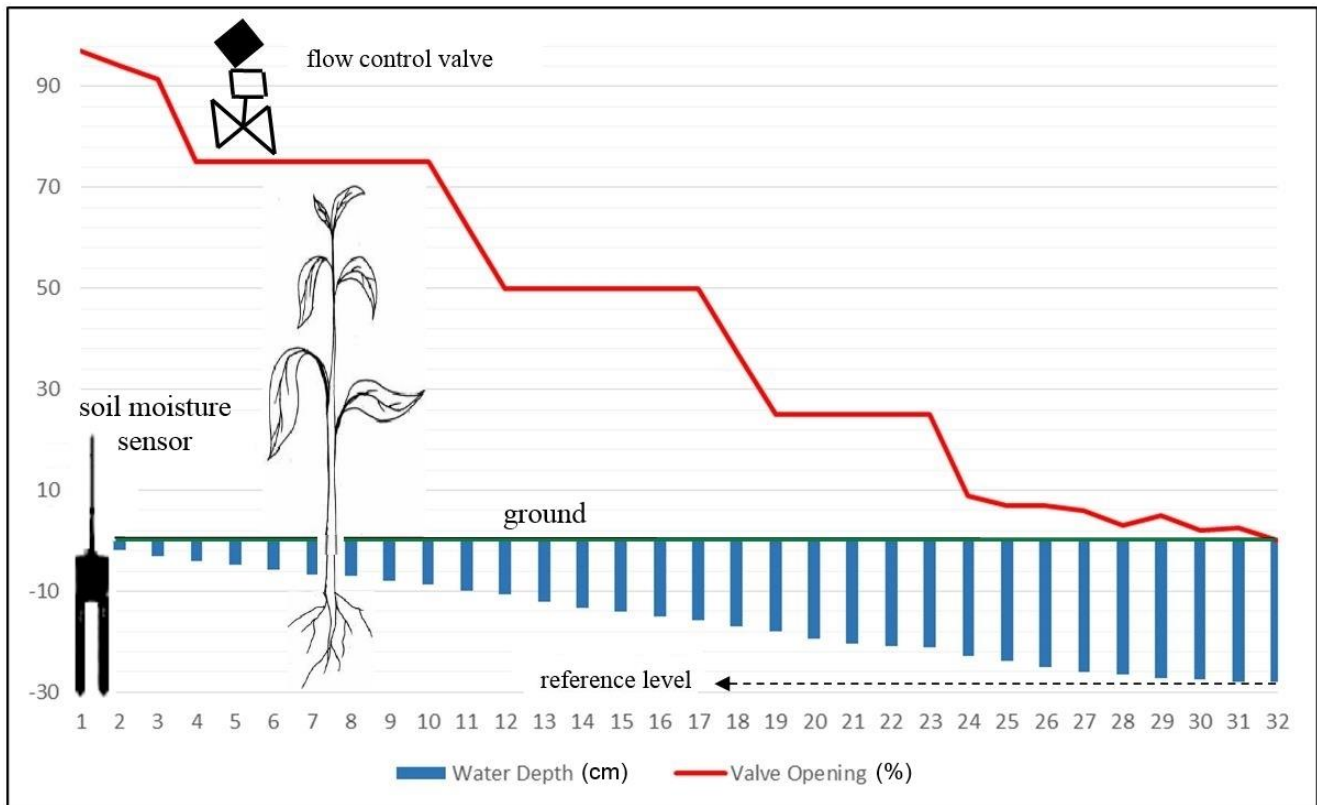


Figure 8: change in the value of water flow valve control signal for the 28 cm reference level on the 32 samples.

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